A Review of Network Models for Internet of Vehicles

Asiya Khan and Sanjay Sharma
School of Engineering
University of Plymouth, Drake Circus
Plymouth PL4 8AA
e-mail: asiya.khan;sanjay.sharma@plymouth.ac.uk

Cindy Goh[1] and Cheng Leong Lim[2]
[1]School of Engineering, Glasgow University,
Glasgow G12 8LT UK
[2]NXP Semiconductors, Singapore 138628
e-mail: cindy.goh@glasgow.ac.uk;
chengleong.lim@nxp.com

***Abstract*—Connected vehicles are the building blocks of the emerging Internet of Vehicles (IoV) under the umbrella of Internet of Things (IoT) and more recently, Network of Things (NoT). This paper applies the NoT concept to IoV networks and presents a review of the network models for IoV highlighting the research challenges and solutions.**

Keywords- IoV; V2V; V2x; NoT; VANET.

I. INTRODUCTION

Automobiles are currently undergoing a revolution just like mobile phones did ten years ago. Future automobile will be expected to communicate with other cars – vehicle-2-vehicle (V2V), with infrastructure/roadside sensors/pedestrians/cyclists/anything else (V2x). The vision of smart cities includes connected vehicles amongst many other things. It is envisaged that 25 million 'things' will be connected by the year 2020. In one year, globally approximately 1.3 million lives are lost and 7.4 million injured in road accidents and 90 billion hours lost due to traffic delays [1]. Therefore to improve road safety and traffic congestion, connected vehicles offer a very promising solution. They also contribute towards the roadmap of fully autonomous driving becoming a reality. The emerging Internet of Vehicles (IoV) is offering the platform to provide real time exchange of information to realize the opportunity of improving road safety and congestion. It has huge applications in autonomous car revolution, intelligent transportation system and smart city.

The key technologies for IoV are presented in [2], guidelines and basic principles of IoV are presented in [3], whereas [4] focuses on the solutions and challenges for connected vehicles. As IoV revolution takes off, the conventional Vehicular Ad hoc Networks (VANETs) are changing into IoV as VANET [5] turns the connected vehicle into a wireless router or mobile node enabling vehicles to connect to each other creating a wireless network between them. An in-depth tutorial on vehicular networking is presented in [6], whereas [7] presents the challenges of integrating connected vehicles to Internet of Things (IoT) and [8] presents a vehicular cloud for IoV applications. There are a number of challenges within the IoV network based on the priority of data exchange messages. For example, priority has to be given to safety critical messages, whereas on-board messages related to infotainment will be lower on that scale. Work presented in [9] proposes an abstract network model for IoV based on individual and swarm activities. Petri-nets have been used recently in vehicular authentication [10], modelling and control of vehicular networks [11] and traffic signal analysis in [12]. Work presented in [13] models vehicular networks using spatio-temporal locality and information-centric networks (ICN) are presented in [14] to model the connected networks. Recently, the concept of Network of Things (NoT) with IoT has been presented in [15]. In this paper, we apply the concept of NoT to the emerging IoV as presented by NIST [15] and review the connected network models presented in literature identifying the challenges and solutions.

The rest of this paper is organized as follows. Section II presents the IoV concept, whereas an overview of the network models is presented in Section III. Section IV presents the research challenges and solutions for network models in IoV. Section V concludes the paper and presents future direction of our work.

II. NOT APPLIED TO IOV

This section presents an overview of IoV, summarizes the wireless channels standards used in V2V and V2x and applies the NoT concept to IoV.

A. IoV Concept

IoV integrates three networks – an inter-vehicle network, an intra-vehicle network and vehicular mobile Internet. Therefore, IoV integrates these three networks and is defined as "a large-scale distributed system for wireless communication and information exchange between V2x according to agreed communication protocols and data standards" [9].

An inter-vehicle network is defined as network communication generated by the vehicle-borne computer, control system, on-board sensors, or passengers that is disseminated in the proximity to other vehicles. An intra-vehicle network is a wireless network between sensors inside a vehicle. A review of intra-vehicle networks is presented in [16]. The number of sensors is forecasted to reach 200 per vehicle by 2020 [1]. Electronic Control units (ECUs) are built in the vehicle which communicates to other ECUs and sensors wirelessly. Connected vehicles require Onboard units (OBUs) to broadcast messages through

 ISBN: 978-1-61208-573-9

VANET. Work presented in [17] shows that vehicle density has an impact on VANET network metrics. The OBUs will contain data such as vehicle location, current time, direction, speed, traffic volume remarks, acceleration, deceleration. The communication between two or more OBUs is the V2V communication and that between an OBU and RSU (Roadside Sensor Unit) is V2I. Recently, the Society of Automotive Engineers (SAE) has established communication standards for connected vehicles (SAE J2725) [18] under Dedicated Short Range Communication (DSRC) for V2V and V2x. Table I summarizes the various wireless communication channels with their requirements for typical communication types, e.g. V2V or V2I, etc.

TABLE I. SUMMARY OF WIRELESS CHANNEL STANDARDS

Channel	**Frequency band**	**Bandwidth**	**Data rate**	**Range**	**Communication Type**
DSRC/ WAVE	5.9GHz	75MHz in USA 30MHz in Europe	27 Mbps (max)	1000m	V2V & V2I/R/ x
Zigbee	2.4GHz/868 MHz (Europe)	2 MHz	20kbps-250kbps	10-100m	V2I/V2R
VLC [19]	400 and 800THz	~390THz	10Kbps (signals) 500Mbps (LEDs)	1000-2000m	V2I/R
Wi-Fi	2.4/5 GHz	20/40 MHz	54Mbps-600Mbps	35m (indoor), 115m (outdoor)	V2V & V2x
4G/LTE	700/800/900/1800/2600 MHz in Europe Supported by IMT and ITU	20 MHz	300 Mbps peak download rates, 75 Mpbs upload rates	Worldwide – limited to cellular coverage zones	V2V & V2x

The sensors in an intra-vehicle communication are stationary so a simple star network topology is sufficient. In this communication type, the wireless protocols that support smaller distance is recommended, e.g. Bluetooth, Zigbee, Radio-Frequency Identification (RFID), etc. A vehicular mobile network is the cloud-based mobile network that sits above both inter-vehicle and intra-vehicle networks. Figure 1 gives an overview of the V2x connectivity using various wireless protocols. The concept behind Figure 1 is that connected vehicles will be able to communicate with each other and with an intelligent transport system (ITS) using different wireless channels such as Wi-Fi, 4G/LTE, etc. and integrated with various sensors. Quality of Service (QoS) in such application will be critical as vehicles come out of one network into the other especially at handover points.

There have been a number of researchers who have exploited both Wi-Fi [20]-[22] and DSRC/WAVE [23]-[26] in V2V and V2x communication. Line of Sight was achieved in [20][21] but when restricted by obstacles (no line of sight) then communication was affected. Work in [22] recommend 10MHz for V2V and V2x. Using WAVE [23], the environmental effects of antenna height, traffic and electromagnetic wave propagation had a severe impact on performance. The WAVE (IEEE802.11p) draft proposal is presented in [24] and in [25][26] authors confirm the viability of WAVE and IEEE802.11 in vehicular communication.

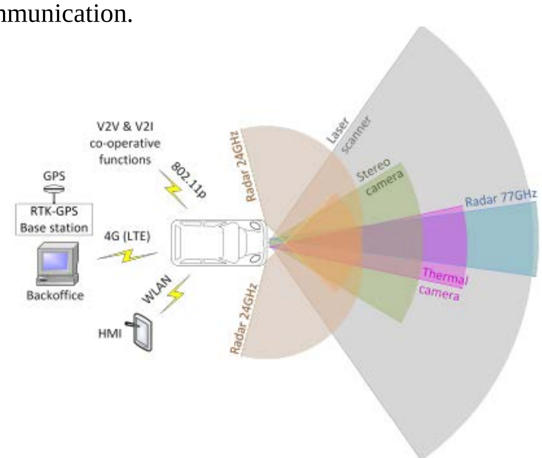

Figure 1. Future trends in connected vehicles [27]

While researchers have presented work on communication protocols, future network models of IoV needs to be compatible with all wireless protocols depending on the communication type e.g. V2V or V2x.

B. *NoT applied to IoV*

The concept diagram of connected vehicles under IoV is presented in Figure 2, which illustrates V2V and V2x connectivity using various access networks, which is in turn connected to the core network. The data is exchanged between Intelligent Transport Systems (ITS) and the vehicles. We link Figure 2 with NoT as presented by NIST [15].

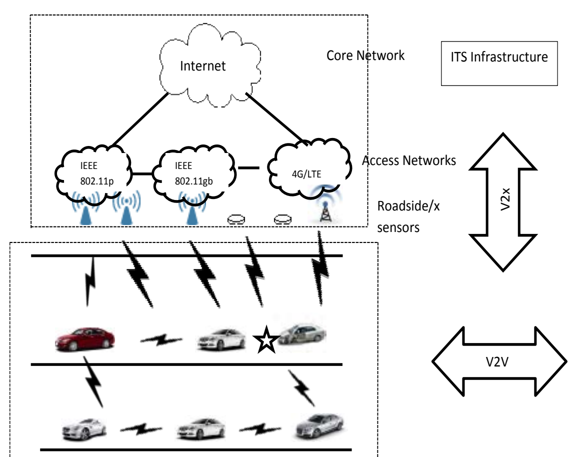

Figure. 2 V2V and V2x concept diagram under IoV

The NoT [15] defines five primitives as Sensors, Aggregator, Communication Channel, External Utility and Decision Trigger. All vehicles will have sensors connected that will be able to transmit/receive 'useful' information. This information is converted by an Aggregator, defined as a mathematical function implemented in software that transforms raw data into some 'useful' meaning. Both Sensor and Aggregator are shown as Roadside sensors in Figure 2. This is underpinned by the communication channel e.g. WiFi, 4G, etc. Again, Figure 2 shows the wireless channels such as Wi-Fi/4G etc. between V2V and V2x. The External Utility can be a software/hardware and will execute processes into the overall workflow of NoT. Finally, the Decision Trigger creates the final result needed to satisfy the requirements of NoT. The External Utility and Decision Trigger is combined together and presented within ITS in Figure 2.

TABLE II. IOV PRIMITIVES

NIST Primitives	Proposed Primitives	Feature
Sensor Aggregate	Sensing Technologies	Wireless and wired, sensors, RFID,
Communication Channel	Communication Channel	DSRC/Wave, Zigbee, Bluetooth, Wi-Fi, 4G/LTE
External utilities Decision Trigger	Data Processing	Data created by connected vehicles, and how it is processed

Based on these NoT primitives [15], we present three primitives. We combine the primitives of Sensor and Aggregator as just Sensing Technologies, Communication Channel and again combine External Utility (eUtility) and Decision Trigger as one and call it Data Processing as shown in Table II. In Table II, feature describes the potential features for each primitive.

III. IOV NETWORK MODELS – AN OVERVIEW

This section presents an overview of the four network models presented in literature.

A. *Petri-Net*

Petri-nets combine a well-defined mathematical theory with a graphical representation of the dynamic behaviour of systems. Precise modelling and analysis of system behaviour is allowed by the theoretic aspect of Petri nets, whereas, the graphical representation of Petri nets enable visualization of the modelled system state changes [28].

Controller Area Network (CAN) communication bus has been modelled using petri nets in [10] and used for timing analysis. CAN [29] is generally used to transmit control traffic between ECUs within the vehicle (intra-vehicle) and is very popular in the automotive application as a communication bus for event-triggered communication. Petri nets offer huge potential for distributed communication which will be key in V2x communication type. For instance, petri-nets cope smoothly with defining and implementing complicated requests in VANET using tokens and measure, i.e. the limits of vehicle numbers of RSU groups.

Figure 3 shows the structure of a distributed control system which includes 2 vehicles, 6 devices, 10 programs and 12 functions with 10 data sets.

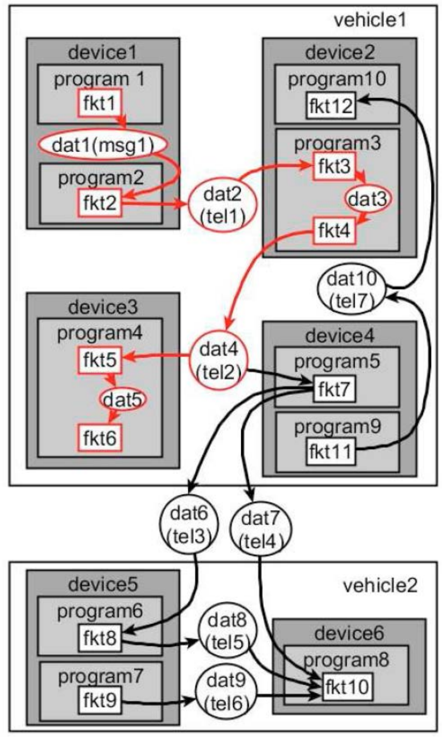

Figure 3. Petri net example of a distributed control system [10]

B. *Information-Centric Networking*

ICN reverses the traditional IP address-centric networking into a content centric one enabling the user to directly retrieve the content using a "name" without referring to the IP address of the node string the content.

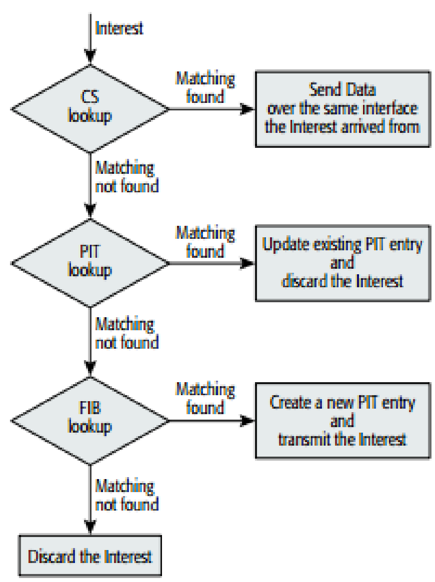

Figure 4. Named Data Networking Interest processing at an intermediate node [14]

 ISBN: 978-1-61208-573-9

This concept sits well with vehicular networks due to poor quality wireless links and the mobility of vehicles, data delivery is challenging. ICN-based VANET concept is presented in [14] where ICN-based VANETs can be applied in areas of application, mobility and security. For example, the VANET data will contain location, time-stamp, etc., so, if the road conditions are sought, ICN can match this better than name-to-IP-address resolution and thus the vehicle does not need to be always connected. The mobility issues in ICN are addressed by the use of named data and therefore, the anycasting and in-network caching properties of ICN allow vehicles to retrieve content from the most convenient storage point. Content-based security is supported by ICN with protection and trust implemented at the packet level rather than at the communication channel.

In Figure 4, a node follows the algorithm, it first looks in its content store (CS) to find a content copy, if a match is not found it looks in the pending interest table (PIT) and eventually in the forwarding information base (FIB). In Figure 4 the Interest/Data exchange refers to a vehicular environment.

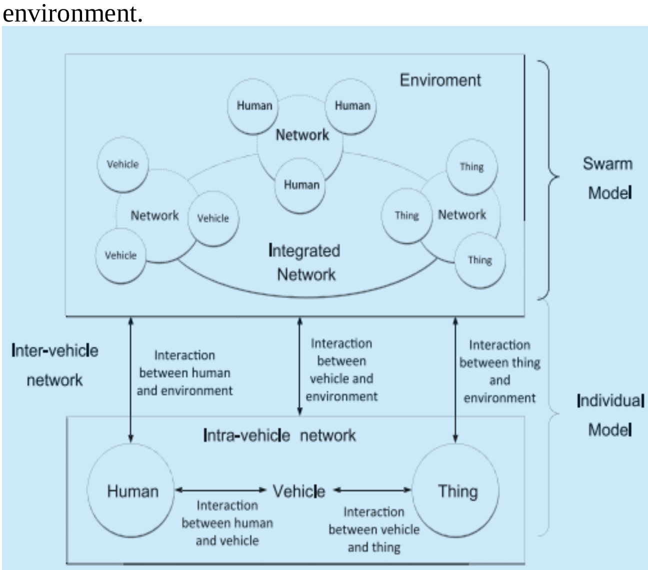

Figure 5. Swarm and Individual Network Model of IoV [9]

C. Swarm and Individual Network Model

The model presented in [9] integrates human, vehicle, thing and environment. The individual model focuses on one vehicle and the swarm model focuses on multi-user, multi-vehicle, multi-thing and multi-network scenarios. Through swarm intelligence, crowd sensing and sourcing and social computing, IoV can provide services/applications. Factors such as network partitions, route failures, change in channel quality and data rate and network load are addressed using swarm intelligence computing at the service providing stage. This is shown in Figure 5.

Authors in [9] also highlight that understanding the service limits is critical for sustainability i.e. network resources under diverse high-dimensional data and limited bandwidth of the wireless network.

D. Cloud, Connection and Clients

Three major network elements of IoV are identified in [30] as cloud, connection and client as shown in Figure 6. The 'cloud' infrastructure provides a platform for a range of wireless access technologies. With the magnitude of traffic related information likely to drastically increase, it is ideal to handle the information using cloud computing framework. 'Connection', on the other hand, utilises Third Party Network Inter Operator (TPNIO) to reduce direct Service Level Agreement (SLA) between the operators of the networks, enabling seamless roaming without compromising the quality and security of network operators. The 'client' element with the help of Wireless Access Technology (WAT) are broadly prioritized and split applications into safety and management oriented and business oriented.

Figure 6. The three network elements of IoV [30]

IV. IoV Network Models - Research Challenges & Solutions

In Section III, we have presented some of the network models from literature. These models were chosen as they show the new paradigm of ICN and the concept of how the proposed network model can communicate both with 'people' and 'things'. Petri-net was chosen as it gives the flexibility for distributed control. The challenge for any network model in IoV is to be able to exchange information from V2V and V2x, where x can be a roadside sensor, another device or a person. In addition, there may be incompatibility among devices, different qualities and response time for Internet connections and limited access to data processing and storage. There will be additional complexity where some vehicles will be connected while others not.

Future and emerging vehicle applications will consume a huge amount of sensor data in a collaborative manner. Content centric [31] and information-centric networks will play a key role. Vehicles move fast, therefore, in a content-centric networking style, vehicle position, speed and direction from the rest of the vehicles are continuously sent. Whereas, ICN focusses on what instead of where to fulfil primary demands from both content publishers and consumers. Vehicular-cloud and ICN will contribute to the 'cloud' to produce advance vehicular services, resource sharing and storing. The proposed architecture for ICN – Named Data Networking (NDN) [32] has been extended to vehicular networks where content is found and not hosts or IP addresses.

ICN seems to be the most favorable network model with distributed control. From literature, we have shown petri-nets [10] used in a number of IoV scenarios. Researchers are leading towards layered architectures [30][33] where network is one of the layers in the IoV architecture. The revealing of location information has huge concerns in vehicle privacy. In addition, location verification of neighbouring vehicle is also challenging due to the absence of trusted authority in vehicular communication. To capture vehicles in line of sight and away from sight presents yet another challenge due to the impact of moving and static obstacles in the network model.

Automobiles are undergoing a revolution by changing the way we think of the cars. Autonomous driving is trialled in developed countries, while fully autonomous driving may be a few years away, some cars will be connected in the very near future, while others not. This will bring challenges in IoV and solutions will have to account for the not connected car. A high volume of data will be exchanged in V2x and data will split between information-rich and safety-critical. Current forms of IP address centric model and control will be challenged due to the dynamic environment of the vehicular data. Therefore, information-centric networking based on distributed control and petri-nets may be the way forward. However, in the short term inter-working between existing networking technologies and information-centric network will be needed. QoS is not guaranteed currently in ICN, and to enable that, software defined networks under the umbrella of network functions virtualization and vehicular cloud networking will be the key enabler.

The integration of automotive and information technology will be promoted as a result of IoV. The biggest challenge in IoV implementation is the lack of coordination and communication. The push for IoV will generate massive data sets. Their analysis will help in the management of traffic systems and towards an intelligent transportation system. The main interactions are between the vehicle and its environment. Hence separate models can be presented in a layered architecture. Some of the challenges identified are:

- Maintaining an accurate line of sight
- Accounting for vehicles/x that are outside the line of sight
- Position/velocity of the vehicle in order to model the dynamic platoon of vehicles
- Vehicles that are not connected
- Security considerations and protection from theft
- Integration of different wireless protocols e.g. DSRC, IEEE 802.11abgn Wi-Fi, 4G/5G cellular networks, VLC
- Device-to-Device (D2D) communication (defined as direct communication between devices in range proximity without the involvement of a network infrastructure) [34] based on LTE
- Safety vs comfort applications
- Integration with cloud architecture
- Big data analysis in IoV
- QoS guarantee – investigate into SDN techniques based on the combined information from multiple sources rather than individual

V. CONCLUSIONS

This paper presents an overview of the network models for connected vehicles under the umbrella of IoV and applies the concept of NoT to IoV. IoV is emerging and will be integrated with information technology. The ‘big data’ generated as a result of connected vehicles will be useful in shaping the management of vehicles thus improving road safety and traffic congestion. The QoS will be split between safety critical and lower priority applications. For example, comfort subsystems within a vehicle are not safety critical. However, suspension and braking system, traction control, etc., will be prioritized and require QoS. Research in understanding existing network models is a key starting point and will enable us in establishing the modelling direction.

IoV is a building block towards the roadmap to autonomous cars. IoV will revolutionize cars like mobile phones did ten years ago. CAN communication model using petri-nets will be further examined for IoV application given its low bandwidth with high reliability benefits.

We will build on this review and the future work will focus on proposing network models for connected vehicles for IoV.

ACKNOWLEDGMENT

The work reported here is supported in part by the Santander Seed-Corn Research Grant.

REFERENCES

[1] Land transportation system report by Cisco http://www.cisco.com/c/dam/global/pt_pt/assets/cisco-connect-2013/pdf/16_outubro_helder_antunes.pdf [retrieved May 2017].

[2] J. W.ang, C. Li, H. Li and Y. Wang, “Key technologies and development status of Internet of Vehicles”, 9th Int. Conf. on Measuring Technology and Mechatronics Automation, 14-15 Jan. 2017.

[3] W. Zhang and X. Xi, “The innovation and development of Internet of Vehicles”, Network Technology and Application, China Comunications, pp 122-127, 13 June 2016.

[4] N. Lu, N. Cheng, N. Zhang, X. Shen and J. Mark, “Connected vehicles: solutions and challenges”, IEEE Internet of Things, Journal, vol. 1, no. 4, pp 289-299, Auguat 2014.

[5] A. Dua, N. Kumar and S. Bawa, “A systematic review on routing protocols for Vehicular Ad Hoc Networks”, Vehicular Communications, vol. 1, no. 1, pp. 33-52, 2014.

[6] G. Karagiannis, O. Altintas, E. Ekici, G. Heijemk, B. Jarunpan, K. Lin and T. Weil, “Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solution”, IEEE Communications Surveys and Tutorials, vol. 13, no. 4, fourth quarter, 2011.

[7] S. K. Datta, R. Pedro, F. D. Costa, J. Harri and C. Bonnet, “Integrating connected vehicles in Internet of Things ecosystems: Challenges and solutions”, IEEE 17th International symposium on a A world of woreless, mobile and multimedia networks (WoWMoM), 21-24 June 2016.

[8] M. Gerla, E-K, Lee, G. Pau and U. Lee, “Internet of Vehicles: From intelligent grid to autonomous cars and vehiclar clouds“, IEEE World Forum in Internet of Things (WF-IoT), 2014

[9] Y. Fangchun, W. Shangguang, l. Jinglin, L. Zhihan and S. Qibo, “An overview of Internet of Vehicles, Vehicular Networking”, China Communication, vol. 11, issue 10, pp. 1-15, Oct 2014.

 ISBN: 978-1-61208-573-9

[10] Y. Kim, Y. Song and J. Lee, "Vehicular authentication security mechanism modelling using petri nets", Indian Journal of Science and Technology, vol. 8(S7), pp. 443-447, April 2015.

[11] P. Diekhake, T. Kurczveil and U. Becker, "Modelling and simulation of distributed time critical communication and control systems in vehicles or vehicle networks", pp. 303-308, IFAC 2016.

[12] M. D. S. Soares and J. Vrancken, "A modular petri net to modelling and scenario analysis of a network of road traffic signals", Control Engineering Practice, vol. 20, issue 11, pp. 1183-1194, Nov. 2012.

[13] Y. Li, M. Zhao and W. Wang, "Intermittently connected vehicle-to-vehicle networks: Detection and analysis", IEEE Globecom, 5-9 Dec. 2011.

[14] M. Amadeo, C. Campolo and A. Molinaro, "Information-centric networking for connected vehicles: A survey and future perspectives", Automotive Networking and Applications, IEEE Communications magazine, vol. 54, issue 2, pp. 98-104, Feb. 2016.

[15] J. Voas,."Network of 'Things'", NIST Special publication, 800-183, 2016. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-183.pdf [retrieved May 2017].

[16] S. Tuohy, M. Glavin, C. Hughes, E. Jones, M. Trivedi and L. Kilmartin, "Intra-vehicle: A review", IEEE Transactions on Intelligent Transportation Systems, vol. 16, issue 2, pp. 534-545, April 2015.

[17] G.Charalampopoulos, T. Dagiuklas and T. Chrysikos, "V2I Applications in Highways: How RSU dimensioning can improve service delivery", 23rd International Conference on Telecommunications (ICT 2016), May 16-18, 2016, Thessaloniki, Greece.

[18] Society of Automotive Engineers, "Dedicated Short Range Communications (DSRC) Message Set Dictionary", J2735 Ground Vehicle Standard, J2735, 2016.

[19] S-H. Yu, O. Shih, and H-M. Tsai, "Smart Automotive Lighting for Vehicle Safety", IEEE Communications Magazine, vol. 51, issue 12, pp 50-59, Dec. 2013.

[20] M. Wellens, B. Westphal, and P. Mahonen, "Performance evaluation of IEEE 802.11-based WLANs in vehicular scenarios", in IEEE 65th Vehicular Technology Conference, April 2007, pp. 1167–1171.

[21] D. Carona, A. Serrador, P. Mar, R. Abreu, N. Ferreira, T. Meireles, J. Matos, and J. Lopes, "A 802.11p prototype implementation", IEEE Intelligent Vehicles Symposium (IV), 2010, La Jolla, CA, USA, June 2010.

[22] L. Cheng, B. E. Henty, R. Cooper, and D. D. Stancil, "A measurement study of time-scaled 802.11a waveforms over the mobile-to-mobile vehicular channel at 5.9 GHz", IEEE Communications Magazine, vol. 46, pp. 84–91, May 2008.

[23] A. Paier, R. Tresch, A. Alonso, D. Smely, P. Meckel, Y. Zhou, and N. Czink, "Average downstream performance of measured IEEE 802.11p infrastructure-to-vehicle links", EEE International Conference on Communications (ICC) Workshops, pp.1 -5, 2010.

[24] D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in IEEE 67th Vehicular Technology Conference, May 2008, pp. 2036–2040.

[25] S. Grafling, P. Mahonen, and J. Riihijarvi, "Performance Evaluation of IEEE 1609 WAVE and IEEE 802.11p for Vehicular Communications", International Conference on Ubiquitous and Future Networks, pp. 344-348, 2010.

[26] K. Y. Ho, P. C. Kang, C. H. Hsu, and C. H. Lin, "Implementation of WAVE/DSRC devices for vehicular communications", in Computer Communication Control and Automation (3CA), 2010 International Symposium on, vol. 2, 5-7 May 2010.

[27] IEEE webinar on connected vehicles Part I and II, Dec. 2015.

[28] T. Murata, "Petri nets:Properties, analysis and applications", Proceedings of the IEEE, vol. 77, no. 4, pp541-580, 1989.

[29] CAN Specification, Robert Bosch GmbH, Stuttgart, Germany, 1991.

[30] O. Kaiwartya, A. H. abdullah, Y. Cao, A. Altameem, M. Prasad, C-T. Lin and X. Liu, "Inter of Vehicles: Motivation, layered architecture, network model, challenges and future aspects", IEEE Access, vol. 4, pp. 5356-5373, 28 Sept. 2016.

[31] V. Jacobson, D. K. Smetters, J. D. Thornton, M. F. Plass, N. H. Briggs, and R. L. Braynard, "Networking Named Content," in ACM CoNEXT, Rome, Italy, 1-4, Dec. 2009.

[32] S. H Ahmed, S.H. Bouk, M. A. Yaqub, D. Kim, H. Song, and J. Lloret, "CODIE: Controlled data and interest evaluation in vehicular named data networks," IEEE Trans. Veh. Technol., vol. 65, no. 6, pp. 3954_3963, Jun. 2016.

[33] J. Contreras-Castillo, S. Zeadally and J. A. G. Ibanez, "A seven-layered model architecture for Internet of Vehicles", Journal of Information and Communication, vol. 1, issue 1, pp. 4-22, March 2017.

[34] T. T. Gunes, S. T. Kwaong U and H. Afifi, "Hybrid model for LT-assisted D2D communications", Ad-hoc, Mobilr and Wireless Networks conference (AdhocNow), vol. 8487, pp. 100-113, 2014.